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GEOSPATIAL ANALYSIS OF SOUTHERN PINE BIOME AND POLLEN DISTRIBUTION PATTERNS IN SOUTHEASTERN UNITED STATES

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The spatial relationship between the parent plants and the distribution of their pollen rain is extremely important for the survival and health of natural ecosystems. In our modern societies there is a continuous and extensive need for wood products, therefore, the health and productivity of the forest ecosystems should be primary concerns for practitioners and researchers. Southern yellow pine forested biomes consist of four major pine species that have been extremely important as American timber sources and as income for the lumber industry. Currently, the intensive harvesting and exploitation of southern pine forests have created a series of highly fragmented forest biome regions. As the distance between individual forest patches increases, the potential intensity of gene transfer decreases. The result is forested patches with limited gene plasticity, which can affect the health of individual trees and of the natural forested ecosystems. The purpose of this research is to establish correlation between spatial distributions of pine forest biome and dispersion of pine pollen. Once the relationship between the pollen rain distributional data and the vegetational biomes are determined, then those correlations will enable researchers to produce projected pollen rain distribution maps for certain regions of North America where existing pollen rain data is absent.

Key words: southern yellow pines, pollen rain, biomes, spatial analysis, splines, zonal statistics, Southeastern United States

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INTRODUCTION

The southern yellow pine biome occupies a vast area of North America extending from the Atlantic coast westward to the forests of East Texas, which end approximately 50 miles west of Nacogdoches, Texas. Southern yellow pine is a collective name used to include four major pine species including the longleaf pine (*Pinus palustris* Mill), the loblolly pine (*Pinus taeda* L.), the slash pine (*Pinus elliottii* Engelm.) and the shortleaf pine (*Pinus echinata* Mill). The first three species are considered native species of southeastern region of the United States. Longleaf pines dominated the pines of this region prior to European colonization and the later arrival of the timber and mining industry. It is the tallest pine of the group, most fire resistant, has a majestic appearance, and is favored for its high wood quality. The major problem with this species is its longer growing period from seed to maturity. Once the original longleaf forests were harvested, they were replaced by faster growing pine species such as the loblolly and slash pines. At the beginning of the twentieth century there was a serious effort to reintroduce longleaf pines into many of the areas where those trees had been harvested (Nees 1927). However, the slow growth rate of longleaf pines, in comparison to the loblolly and slash pine, made further planting of this native species economically impractical in spite of the plant's high adaptability to the wide variety of soil conditions in the south.

The replacement of longleaf pines with the faster growing loblolly and slash pines resulted in the southeastern region becoming a major supplier of timber for mills and the lumber industry. Today, the United States is the leading producer of timber in the world and the southern states are a major supplier of softwood for this market. The majority of current softwood products (lumber, veneer, plywood) are harvested in the southeastern region of the United States where the state of Louisiana is the regional leader. Lumber from the southern pines is marketed throughout the United States and is exported to China, Japan, and Europe. It is highly prized because the southern pines excel in characteristics such as high strength, durability, appearance quality, nail holding ability, etc.

The viability of the southern pine forests depends on the successful development of seeds and growth of seedlings. These come from fertilization, which is highly dependent on pollen reaching its intended targets and completing the fertilization process. The earliest pine trees, which first emerged during the Carboniferous Period (359-299 million years ago) developed male cones that produced and dispersed millions of tiny pollen grains into to wind in hopes that a few of them would reach the female eggs and complete the fertilization process. This ancient method of pollen dispersal is still carried out each spring by pines. Thus, to ensure adequate pollination, the pines have become prolific producers of large quantities of pollen. Once dispersed, pine pollen is subjected to a number of variables that will affect its ultimate geographical distribution as part of the local pollen rain. Some of the critical variables include prevailing wind direction and speed, humidity, landscape topography, pollen morphology and mass, and obstacles in the pollen's path, such as branches, leaves, buildings, and other man made structures.

Plant pollen plays a critical role in fertilization and genetic transfer; therefore adequate pollen distribution plays an important role in maintaining healthy, natural ecosystems. Pollen and the nectar in flowers also play important roles because they become a source of food for many insects, some species of birds, and a few mammal species. The spatial distribution of pollen distribution can be captured and plotted using GIS techniques. Recently, a significant body of surface pollen distributional data has been compiled and is now available (Whitmore et al. 2005). These surface pollen distributional data reflect the natural pollen rain for each target location and provide valuable clues about the local and regional vegetational composition of wind-pollinated plant species. In regions where favorable soil and microbial environments exist, pollen from gymnosperms, angiosperms, and spore-dispersing cryptogamic plants can be preserved for thousands or millions of years. In those areas the preserved pollen in the sedimentary records becomes one of our most important tools for reconstructing paleoenvironments.

Beginning in the 1960s a number of palynologists began experimenting with the construction of isopol maps using surface and later subsurface fossil pollen data to project spatial variations of pollen distributions. As more pollen data became available, new isopol maps plotting the distribution of different pollen taxa began appearing in publications for different regions, yet the most pollen data and greatest detail were available for areas of Eastern North America (McAndrews and Webb III 1976). One of the first monographs on this topic was an atlas of maps published by Delcourt et al. (1984). A number of research papers followed that lead and began focusing on various types of computer simulations and programs for modeling pollen dispersal and pollen accumulation rates over the landscape, and how those data could be used to predict changes in vegetation, and by inference climate. A few examples of articles during this period include the efforts by Sugita et al. (1999) and Jackson and Lyford (1999).

One of the first efforts to apply GIS techniques to pollen distribution patterns was the effort by Siska et al. (2001). In that study, limited surface pollen distributional data was used to generate geostatistical modules in GIS that predicted pollen depositional patterns over a large region of the Big Bend National Park in west Texas. Later, Boyd and Jago (2003) used GIS techniques to construct a pollen distribution atlas for *Ficus* and a few related plant species.

Traditionally one of valuable uses and applications of pollen analyses is in the reconstructing of past vegetation patterns with the intent of using those data to infer past climatic changes. This type of application has been most frequently applied to the periods of the Holocene and late Quaternary (Bartlein et al. 2004). Part of the validity for using pollen data in paleoenvironmental reconstructions is based on the observation that specific plants and composite vegetations thrive best in ecological zones that most favorably meet their needs. A second reason comes from the assumption that evolutionary changes, and by inference ecological needs, in plant species occur slowly over long periods of time.

Geographic Information Systems' capabilities support the input and analysis of multilevel spatial information and therefore can be useful for analyzing the special relationships between pollen distribution and vegetational composition. For example, Fyfe (2005) used coarse resolution of digital elevation models to determine the influence of topographic relief on pollen distribution and deposition using landscape simulations. The site analysis of this example, based on relief properties, appeared to play a significant role in the reconstruction of landscapes and for testing it against archeological and paleoecological theories.

DATA AND OBJECTIVES

The purpose of this project is to study the spatial relationship between the important pollen taxon (*Pinus*) and recent forest patterns in the southeastern United States. During the last several centuries the southeastern forest ecosystem has been severely affected by anthropologic activities that resulted in the significant fragmentation of the forest and in changing gene flow patterns. The trees, such as pine, which are wind-pollinated, are an important component of the natural ecosystem in this region and maintaining the genetic variability of individual plants is important for the survival of the entire biomes.

Destruction of continuous vegetation cover and fragmentation of forests contribute to areas of isolation and genetic restrictions, which are caused by inbreeding and can, therefore, lead to genetic drift and restricted gene flow (White et al. 1999; Boshier et al. 2002). Therefore, a major purpose of this research is to evaluate the efficiency of pine forest pollen distributional patterns by analyzing the spatial relationships between the forest and pollen distributions. The example of a similar study can be found in the research conducted by Mack and Bryant (1974). They studied the pollen rain and resulting pollen spectra in the large, semi arid grassland biome in central Washington, known as the Columbia Basin. That study found that a significant amount of pine pollen was dispersed and deposited into the mostly deforested region of Columbia Basin from the nearby mountains where pine forests dominate the lower elevations. As noted in their research, the percentages of pine pollen deposited throughout the Columbia Basin depend on prevailing wind patterns, distance from closest pine forests, and the overall pollen concentration at each sampling location. The authors also emphasized the need to understand existing pollen percentages in relation to the type of existing vegetation cover.

The data used in this project were acquired from the North American and Greenland database compiled and developed by Whitmore et al. (2005). This database contains pollen distributional records for 4,634 specific locations in North America. For each of these locations, the pollen analysis of surface samples focused on the recovered pollen from the most common 134 plant taxa, found in much of the flora of North America and the ice-free regions of Greenland. Although a few other pollen taxa were found in some of the samples, those other taxa outside the basic 134 were not included because they were rare types that occurred in only a few locations. The total

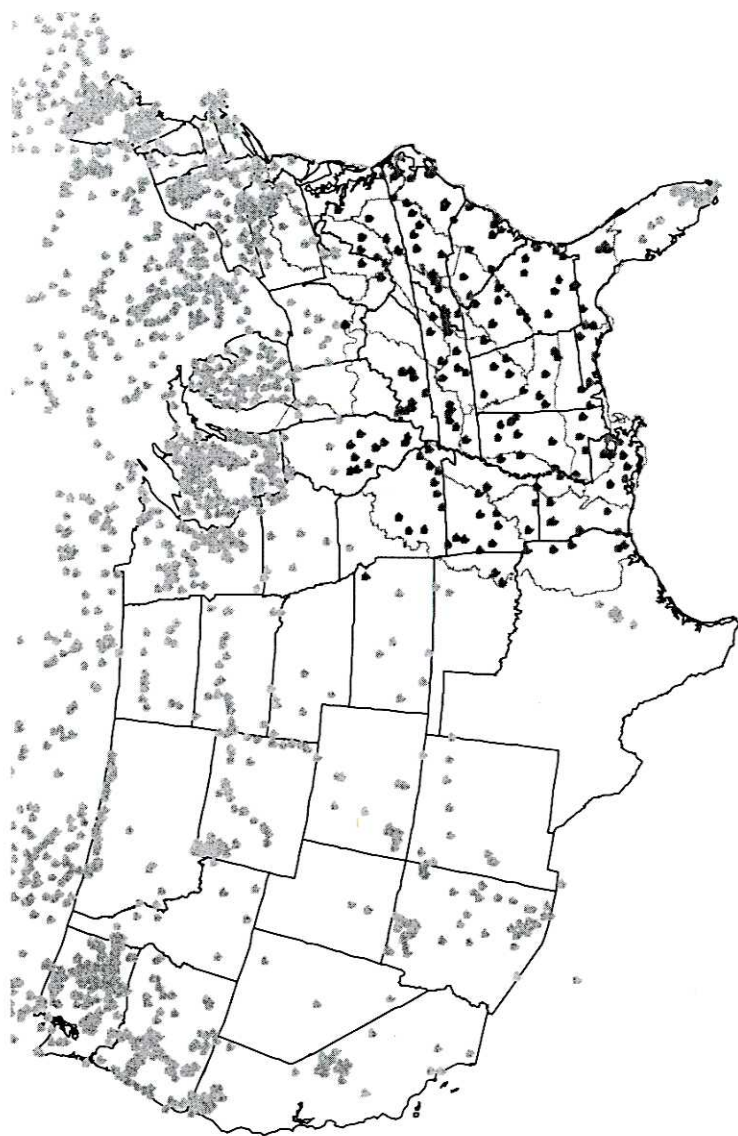


Fig. 1. Study area and location of point data from surface pollen samples



Fig. 2. Distribution of forest types in the Southern U.S.

ber of pollen grains examined and recorded as part of the 4,634 samples is 2,231,415. Besides recording pollen grain counts, this dataset also contains many other attributes of spatial relevance including bioclimatic data, broad-leaf and needle leaf forest percentage cover and more.

The dataset used in this study consists of discrete data points that were imported into GIS and further analyzed using variogram modeling and kriging subroutines in a geostatistical analyst to obtain continuous surface representations. The collection of these data from individual sampling sites in the forests in the southeastern part of United States can then be expressed on maps indicating the maximum and minimum amount of pollen distribution and accumulation. Fig. 1 shows the study area as a shaded region. The dots represent sampling locations of existing pollen distributional data for United States and southern Canada, including the distribution of airborne pollen types in the study region. Another aspect of our research will be to develop a method, based on GIS, which would evaluate the co-regionalization of pollen distributional patterns with forest vegetational patterns. In this respect, our planned work will be similar to the research conducted by Jackson and Williams (2003) in their study and comparison of the relationships between modern vegetational gradients (derived from remote sensing data) and pollen distributional patterns in North America.

The second dataset regarding the forest cover in this region came from records retrieved from the National Atlas (www.nationalatlas.gov). These data are available in geo-referenced raster format with a spatial resolution of one kilometer. The detailed information about acquisition and development of this dataset can be found in Homer et al. (2001). Our Fig. 2 shows the distribution of classes of general forest cover as well as water and non-forest lands in the southeastern United States.

The map produced in Fig. 2 was derived using Advanced Very High Resolution Radiometer (AVHRR) composite images and Landsat Thematic Mapper (TM) data from the 1991, growing season (Zhu and Evans 1994). For the purpose of this project, the forest type map was reclassified for the southeastern part of the United States from 25 types into six categories including pine, oak, elm-ash-cottonwood, spruce-fir, lakes and non-forested area. The mesophytic, broadleaf elm-ash-cottonwood deciduous forest is located mostly in the northern part of this region followed by zones of oak and pine found mostly in the piedmont region of northern Alabama, Georgia and the Carolinas. The southern evergreen forest, which is dominated by *Pinus palustris*, *P. taeda*, *P. echinata* and *P. elliottii*, accompanied by oak (*Quercus*), hickory (*Carya*), magnolia (*Magnolia*), sweetgum (*Liquidambar*), ash (*Fraxinus*) and maple (*Acer*) occupies the Deep South all the way to the Gulf of Mexico.

The forest type map reveals that over 550,000 square kilometers is occupied by the oak forests (an area equivalent to the country of France) and almost 300,000 square kilometers (approximately the area of Poland) of pine forest still remains in the southeastern part of United States. Those forested regions, however, are rapidly becoming more fragmented than they already are. More disturbing, is the current image analyses indicating that the non-

forested areas in the Southeastern U.S. now compose the largest portion in the region (678,000 sq. km).

METHODOLOGY

From the data set of 4,634 pollen samples collected for the North American and Greenland project, a subset the 204 samples were selected for our use in this project. All 204 samples are located within the study area of the southeastern region of the United States, which is the area we examined. The modern pollen data reveal that the distributions of pine and oak pollen reach their highest frequencies and are the most abundant in the southeastern region (i.e., a total of 31,792 pine pollen grains vs. a total of 22,078 pollen grains for oak). For the purpose of this study, we combined the pine pollen into one category, which includes both diploxylon and haploxylon types as well as all pine pollen grains that could not be assigned to either of those two major groups. When considering the entire North American pollen dataset, 23.14 % of all the oak pollen occurs in the southeastern US region yet only 6.7 % of all the North American pine pollen accumulates in the southeastern US study area.

There are other major airborne pollen taxa fir (*Abies*), birch (*Betula*), beech (*Fagus*), spruce (*Picea*), oak (*Quercus*), hemlock (*Tsuga*), and grasses (Poaceae) that have overall lower pollen distribution percentages in the southeastern region than the pine pollen (8.76 %). *Picea* is an important pollen type in some regions of the North American continent, but in our study area, *Picea* pollen is insignificant and is reflected by overall totals of less than 0.03 %. Another example of low representation in the southeastern region is *Fagus*, which is represented by less than 2 % of the total recovered pollen. This is, however, consistent in comparison to the pollen quantities for the entire North American continent and Greenland. As seen in Figure 3, *Fagus* is one of the weakest arboreal pollen types represented in the North American and Greenland database, whereas *Pinus* is the highest arboreal pollen producer with nearly one-half million total pollen grains recovered in the database. That difference suggests one is 38.5 times more likely to find pine pollen than *Fagus* pollen. *Betula* is the second highest arboreal pollen type represented, while *Picea* is the third highest arboreal pollen type found in the North America and Greenland database.

An interesting aspect of spatial analysis is to examine covariation, or co-occurrence, of different taxa across the North American continent using Pearson correlation coefficients (Equation 1) that is frequently used to summarize linear relationship between two variables at hand (Isaaks and Srivastava 1989). The variables X and Y represent quantities of two pollen taxa, and coefficient “*r*” determined the strength of linear relationship between both variables. When this is done, the correlation between the different forest pollen taxa in the southeastern part of United States maintain the same values, with minor differences, as the ones found for the entire North American continent. The strongest correlation in the southeastern region, as determined by using Pearson correlation coefficients, is between *Betula* and *Tsuga* (hemlock) pollen $r = 0.72$ (i.e., an increase or decrease of *Betula* pollen is accompanied by an increase or decrease of *Tsuga* pollen).

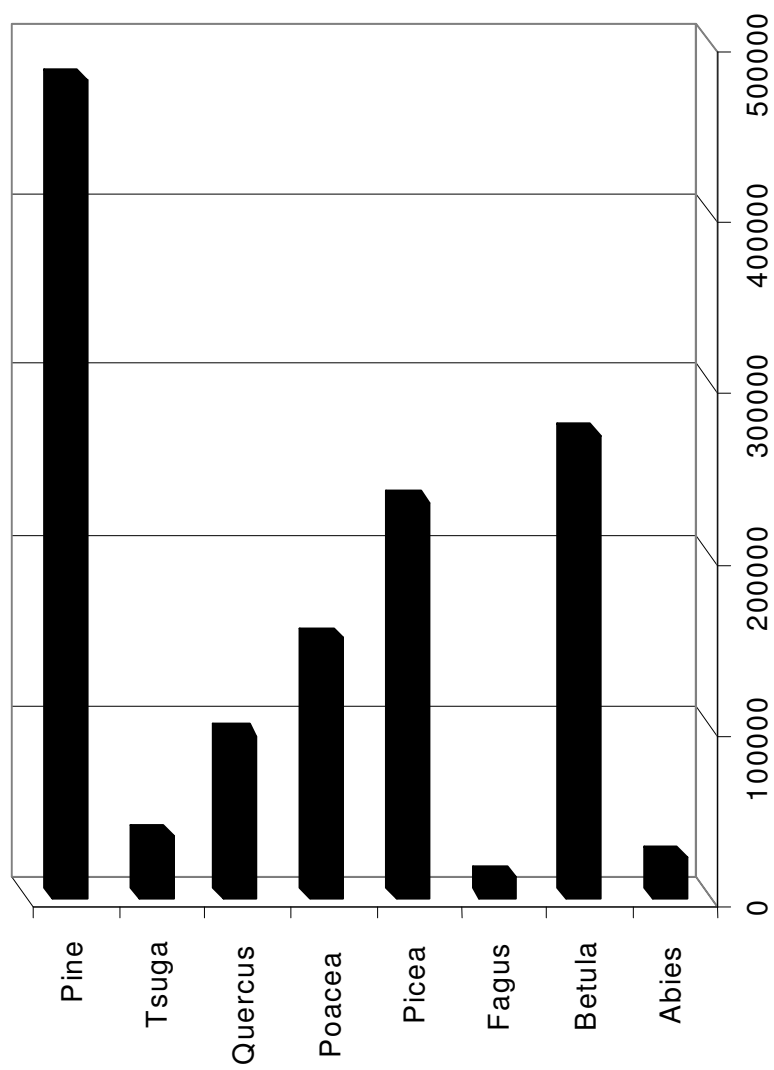


Fig. 3. The total amount of pollen grains for individual taxon

$$r_{x,y} = \frac{n \sum xy - \sum x \sum y}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}} \quad (1)$$

The overall relationship between pine and oak pollen is very weak ($r = 0.04$) for the southeastern forested regions. On the other hand, the oak and beech pollen correlation is significantly stronger ($r = 0.36$) (i.e., suggesting the amount of beech pollen is related to the amount of oak pollen in the study area). The Pearson values indicate that both hemlock and birch are strongly influenced by changes in elevation, and probably the climatic factors related to elevation. The correlation value of 0.8 for birch indicates that in the southeastern regions, elevations seem to be a very important factor in explaining pollen distribution, and by inference vegetational associations. As the topographical relief becomes more diverse and the elevation increases, birch pollen becomes more abundant. This correlation applies also for hemlock, which is reflected by its correlation with elevation of 0.67.

The point-sampled data represent an isolated form of information that is difficult to interpret spatially. This includes surface pollen samples that are usually collected from point locations and then the pollen data is reconstructed for that location. To evaluate spatial distributions of natural phenomena, and its relationship to other environmental factors, discrete forms of information must be converted into a continuous surface by using sophisticated interpolation algorithms such as the inverse distance method, and the family of best linear unbiased estimators such as kriging or splines. For this project, a completely regularized spline interpolator was selected to model the distribution of pollen taxa (pine) in the studied area. The reason for selecting this interpolator is purely empirical. Since the variogram model (Fig. 4) did not fit the sample data well, we excluded the kriging group of interpolators and looked for solutions among one of the spline interpolators, which is available in geostatistical analyst. The use of splines has proven effective for the study of large areas (Burrough and McDonnel 1998) and splines are frequently recommended in GIS literature (Chang 2004, Burrough and McDonnel 1998) for acquiring smooth, cartographically-attractive surfaces. In addition, splines (regularized and thin plate splines) are programmed and available in many GIS types of software where they are used frequently for generating continuous surfaces from point data. Unfortunately, these programs do not list or properly explain the exact mathematical algorithms for each function or its importance for any particular problem at hand. As a result, many practitioners and researchers tend to use these functions as “black boxes”; often lacking mathematical understanding of these functions and the limitations of these spatial interpolators. On the other hand, the purpose of developing complex and sophisticated interpolators such as kriging and splines is to make them available to a large community of users that produce numerous geospatial analyses for natural resource management applications.

In this research several options were empirically tested for interpolation and the best results, in terms of root mean square error, were generated

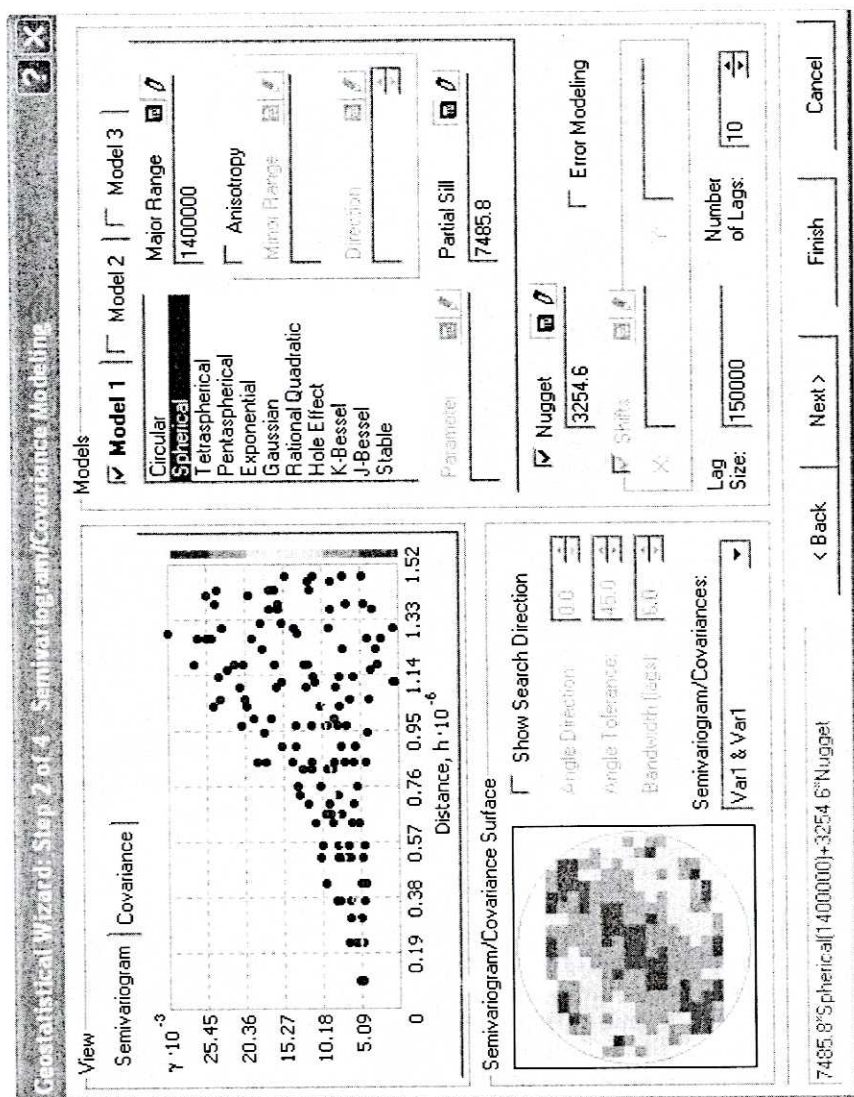


Fig 4. Variogram of pine pollen data

using completely regularized splines (CRS) derived by Mitasova and Mitas (1993). As the authors indicate, this method includes a tension parameter that controls the character of the interpolation function. The flexibility and accuracy of this method is also presented herein. Due to these properties, regularized a spline is also appropriate for use in terrain modeling, as demonstrated in Mitasova and Hofierka (1993).

We considered several spline functions for interpolation of the pollen data and decided to use the completely regularized spline (CRS) that is available in geostatistical analyst. The decision was based on the smallest root mean square error and smooth cartographic appearance that plays a significant role in data presentation.

RESULTS

The continuous surface of a single pollen taxon (pine) is represented in Fig. 5. The results indicate that the pine pollen tends to accumulate near the coastal areas. There are two major concentrations in the southeastern region. The first, and largest, concentration is in the eastern and southeastern areas covering a region to the Atlantic coast from a western point between the cities of Raleigh, North Carolina in the north and Columbia, South Carolina in the south. As the prediction map indicates, the total quantity of pine pollen in the samples from this area reaches over 2000 grains.

The second important patch of pine pollen density is located on the boundary between Georgia and Florida. The extent and total concentration, however, is not as pronounced as seen in the first major region. In this second region, the density of pine pollen gradually decreases northward towards Tennessee and westward toward Alabama. Note that in Fig. 5, there is a significant decline of pine pollen estimated for areas along the border of the state of Mississippi with both Louisiana and Arkansas. This lower pine pollen accumulation may reflect large areas of deforestation along the Mississippi river extending down toward the delta region. In addition, the agriculture production of crops such as cotton and maize has led to much of the deforestation further north along the Mississippi River extending into the Upper Midwest.

Synthesis

The purpose of this analysis is to study the relationship between the spatial distribution of pine forests and the spatial dispersion of pine pollen in the Southeastern U.S. and to search for correlations between the low percentages of pine pollen, and by inference low flow of genetic material, and forest fragmentations. Our map in Fig. 2 was constructed from the National Land-Cover Database (Homer et al. 2004) and was then reclassified for the purpose of this project. To achieve a composite synthesis of geographic information, we used a map overlay method in GIS to combine spline interpolated pollen distribution patterns and the satellite-based reclassified land cover map (Fig. 6). The results indicate that the distribution of major forest pollen taxa and the corresponding mother-forests are covariate only to a

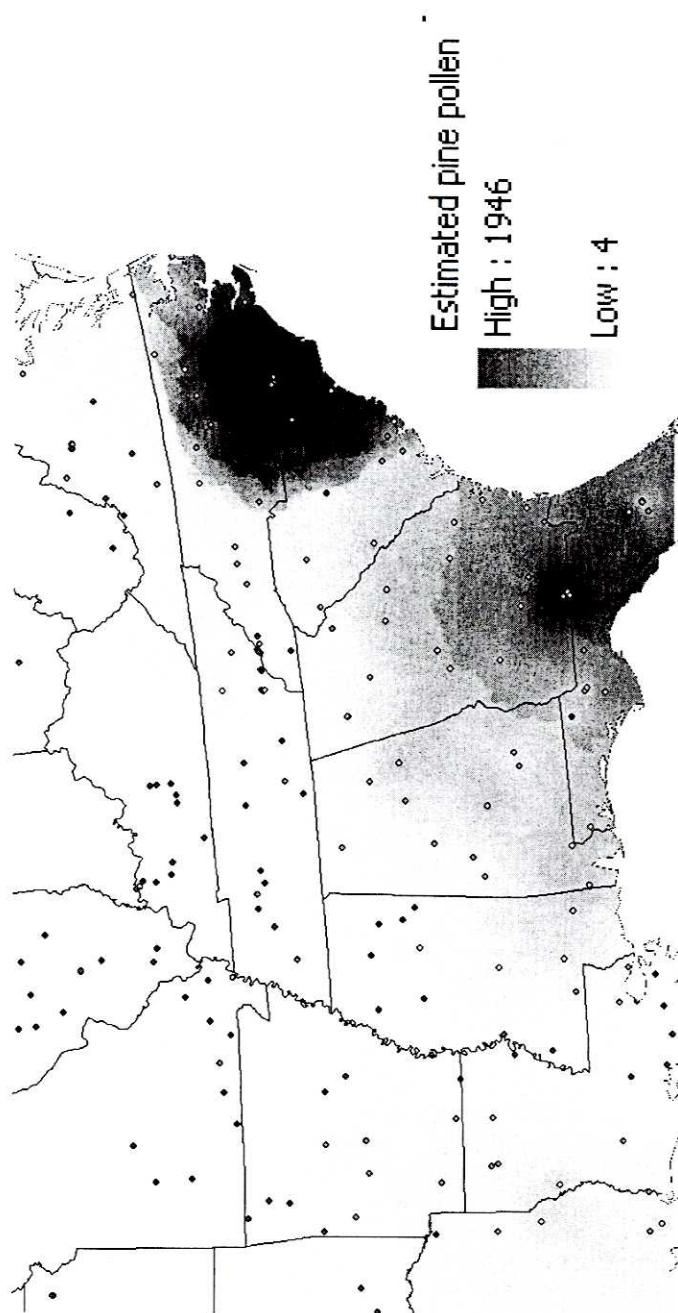


Fig. 5. Spatial distribution of pine pollen in the Southeastern Region of the United States.

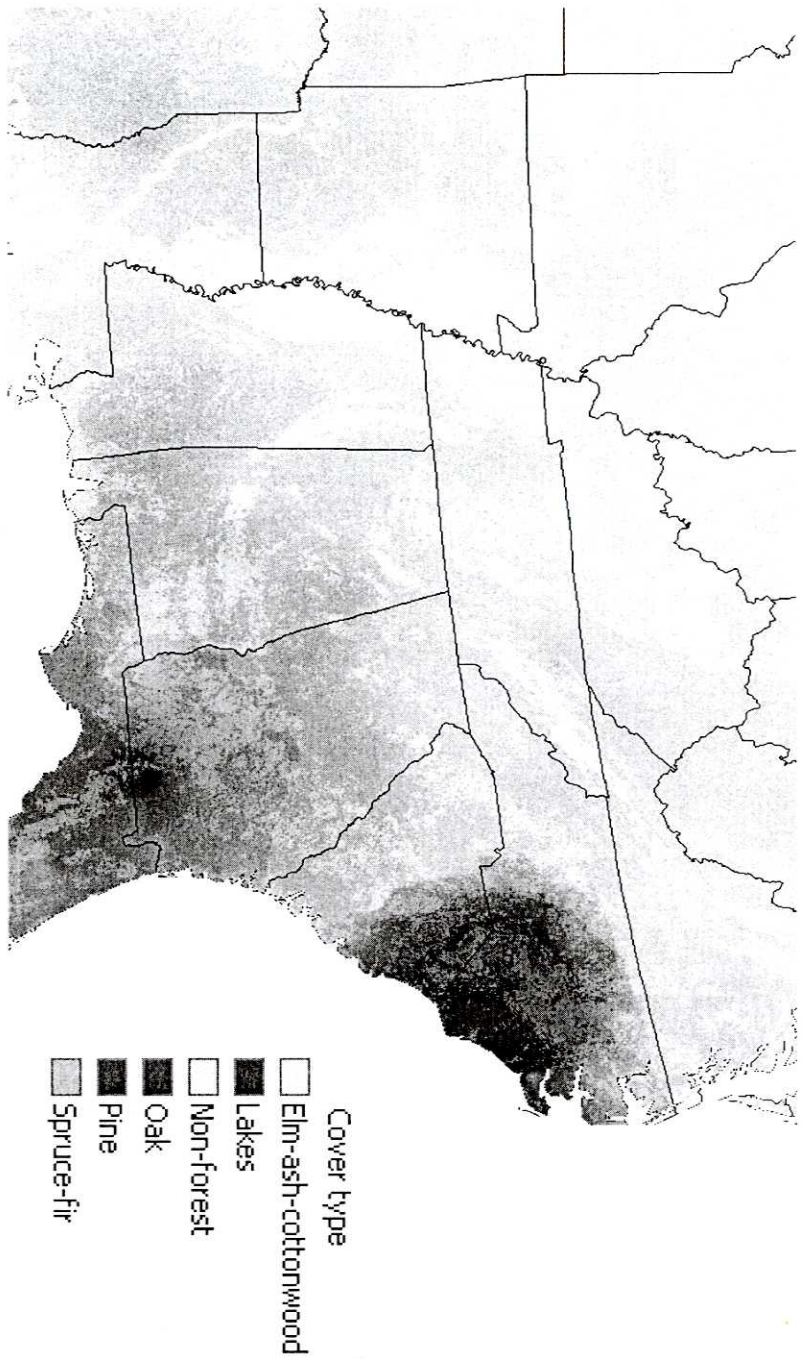


Fig. 6. Spatial synthesis of pine pollen and forest cover

limited degree. For example, the highest concentrations of pine pollen do not correspond well with known pine forests in this region, except for the southern coastal area of North Carolina.

On the other hand, the continuous pine forests in the central and western areas of South Carolina and Georgia do coincide with higher percentages of pine pollen found in surface samples. A similar correlation is evident for the Gulf Coast regions of Alabama and Mississippi. However, we were surprised that the thick, continuous pine forests growing west of the Mississippi River, in Louisiana and in East Texas, were represented by low percentages of pine pollen in the surface sample counts (Fig. 5).

As indicated previously, the Mississippi River valley and its delta region represent a spatial entity with very low covariation between pine pollen and pine forests. This we believe reflects the region's wide open and intensively-used agricultural areas.

Zonal Statistics

In an effort to determine the quantitative spatial relationship between the frequencies of any two pollen taxa and the spatial co-distribution of forest vegetation, we selected the zonal statistics function using spatial analyst GIS to capture the quantities of pine and other major forest pollen types. We included non-forested areas and water (lakes) in this analysis database. The results indicate that the primary area, with the highest percentages and majority of pine pollen are in the regions with pine forests. The secondary area, containing somewhat lower amounts of pine pollen is composed of the oak forests. The third area is the small water bodies, mostly lakes, with minor amounts of pine pollen, which are estimated to be less than a total of 100 grains in the combined counts. Some of the pine pollen is deposited in non-forested areas, such as the urbanized regions in the Southeastern U.S. Finally, the smallest amounts of deposited pine pollen in the Southeastern region of the U.S. are in the areas dominated by Spruce-Fir forests and the Elm-Ash-Cottonwood forest biome. The composite map of pine pollen and vegetation types (Fig. 6) shows the overlapping areas between these two components and highlights the mismatch areas where the low pollen values coincide with high density forested biomes or visa versa.

The areas of strongest forest destruction and fragmentation can be compared and evaluated with respect to the amounts of forest pollen types that each vegetation type receives. This, we believe, is one of the useful features of our analysis because it can suggest gaps in the pollination efficiency of arboreal components in forest, which may affect the successful transport of sufficient variety of genetic material between isolated forest patches.

The zonal statistics of oak pollen vs. oak land cover indicates a different pattern of spatial match-mismatch (Fig. 6). The pollen data and spatial analysis of the oak pollen distribution seems to be fairly evenly distributed over the different areas of forests and other land cover categories. This type of correlation does not seem as uniform for some of the other arboreal pollen types. Oak pollen distribution is fairly high in the areas assigned to

Spruce-Fir forests, which is mostly a factor of long distance transport of the oak pollen from nearby forested areas. The areas in the Southeastern U.S. that are mostly pine forests receive the lowest amounts of oak pollen, which is to be expected because pine trees produce and disperse far greater amounts of pollen than do oak trees. In addition, the total amounts of pine pollen produced in pine forests will total dominate any other pollen type being produced and dispersed.

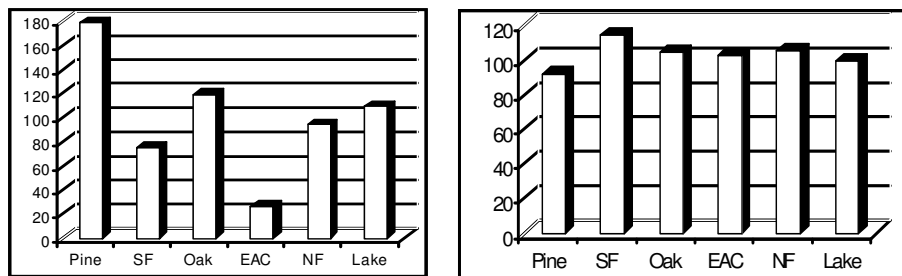


Fig. 7. Comparisons of pine (left) and oak (right) zonal statistics. Vertical axis determines the mean estimated pollen magnitude in corresponding forest type categories

(SF: Spruce-Fir, EAC: Elm-Ash-Cottonwood and NF: is Non-Forested).

Future Project

Researchers in natural sciences, such as palynology, are often facing a difficult task when trying to make inferences for many variables based on the available data from only one variable. These types of problems are examples where knowledge of the relationship between pollen distribution and actual vegetation would allow us to predict the pollen quantities based on remote sensing data based on vegetation cover. Currently, the field research necessary to gather actual data is becoming increasingly time-consuming and expensive. Therefore, the logical future trend is to increase the usage of remote sensors to map and evaluate quantities of environmental variables. In our study we have attempted to propose the ground work for establishing correlations between the spatial distribution of pollen types and the actual vegetation cover they represent, which would greatly limit the need for actual field work. In pure mathematical terms, the ideal method is to collect these data in the field and then work with the actual ground data using the above described functions such as splines. However, future applications and needs for these types of data will exert a tremendous amount of pressure on geospatial analysts to maximize their analyses with a minimum amount of field work. If such trends continue, the demand to produce results without actual field sampling will increase the need for available technology and GIS applications.

Our study and analysis provides a general evaluation of the spatial co-behavior between wind-pollinated, arboreal pollen types with the actual plant sources for the Southeastern U.S. and how those two variables are in-

fluenced by various types of land cover. To refine the spatial covariation between these two important components of an ecosystem, we propose a new method to determine the spatial covariation between pollen dispersion and corresponding spatial distribution of parent plants. It is based on a regular grid, or moving window system that would be “dropped” onto both data layers (pollen and land cover). In that way, the quantity of pollen in relation to the percent and type of land cover would be measured in each grid cell on moving windows. Due to the scarcity of data, the results from the interpolation should be used to determine the relationships exhaustively across the study area. The potential use of Dirichlet-Voronoi polygons, which will be generated in GIS around each point sample containing pollen values, may also be considered. The average quantity of pollen will be evaluated in each polygon. In the next step the biometric values, such as the percent of vegetation cover and the imperviousness will be extracted from a NLCD database. The database will consist of quantitative biometric measurements that will help to establish a model using multiple linear regressions. Such a model can then be useful for determining the tightness of associations between spatial dispersion of pollen and the vegetation cover. The amount of pollen at each point can then be expressed as a function of vegetational parameters. Once such a relationship is established, palynologists will be able to use maps predicting the amount of pollen in particular areas based on land cover biometric characteristics. Currently, trying to construct these types of data using available field research is time-consuming and costly. Conversely, remote sensing images are readily available.

Other plans for our future research include studying the sinking speeds of the major arboreal pollen types in an effort to determine their ability to disperse over long distances from their sources (Jackson and Lyford 1999). Also needed is a better understanding of the scavenging effects of obstacles (both natural and man made) that will limit the distances and amounts of dispersed pollen in forested and non-forested areas (Tauber 1967).

CONCLUSION

Pollen dispersion and vegetation are both important components of a natural ecosystem. Healthy forested areas in the Southeastern U.S. are composed of many wind-pollinating species that produce large amounts of pollen. Normally, high pollen production, combined with normal wind dispersion methods, guarantees effective pollination and the production of seeds with a high genetic diversity. During the last two centuries human activities have severely disrupted the natural ecosystem in many regions of North America, including the Southeastern region. The results of these modifications have been the fragmentation of continuous forests and the formation of forest patches in many areas. The reduction of vegetation cover has also increased the amount of carbon dioxide that is released into the atmosphere, which contributes to global warming (Murty et al. 2002 and Lal 2001).

When examined together, these two aspects (i.e., remaining forest cover vs. the expanding amounts of non-forested areas) make the study of pollen dispersal and distribution important. Derived data from these studies can be

used to determine the genetic plasticity within forest patches, and the essential criteria that are needed to keep the forested ecosystems in the Southeastern U.S. healthy and viable. One of the first essential tasks is to develop effective methods of mapping the variables of pollen distribution vs. forest cover. The production of reliable maps of this type will help those in the lumber industry, those wanting to protect areas of old growth forests, and will enable researchers in forestry to plan effectively for the future.

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PRIESTOROVÁ ANALÝZA EKOSYSTÉMU BOROVÍC A ICH PEĽU V JUŽNEJ ČASTI SPOJENÝCH ŠTÁTOV AMERICKÝCH

Lesné porasty sú dôležitou súčasťou zdravého životného prostredia a zároveň plnia aj praktickú funkciu ako surovinová základňa pre drevársky a papiernický priemysel. Udržiavanie zdravých lesných porastov je preto jedným z hlavných cieľov prírodovedného výskumu, ktorý efektívne využíva diaľkový prieskum Zeme a geografické informačné systémy. Predložená práca sa zaoberá štúdiom priestorového rozloženia borovicových lesov a borovicového peľu v juhovýchodnej časti Spojených štátov amerických. Tento región sa vyznačuje hustými porastami borovicových lesov, ktoré zaberajú tisíce štvorcových kilometrov od brehov Atlantického oceánu v štáte Severná Karolína až po hranicu medzi východným a stredným Texasom. Koncom 18. a začiatkom 19. storočia ťažba dreva dosiahla najväčší rozvoj a zanechala borovicové lesy devastované. V súčasnej dobe je tento rozsiahly ekologický systém čoraz viac fragmentovaný, najmä v súvislosti s urbanizačným a priemyselným rozvojom. Aj napriek tomu, že úpadok tabakových plantáží na juhovýchode je spomaľovaný čiastočným zalesňovaním, intenzita rozkúskovania súvislého lesného ekosystému sa postupne zvyšuje. Tento proces fragmentácie má za následok obmedzovanie toku rastlinných génov, čím sa ohrozuje genetická plasticita a zdravie stromových porastov v izolovaných lesných regiónoch.

Cieľom tejto práce je zhodnotiť situáciu priestorového rozloženia borovicových peľových zrníek v skúmanom území vzhľadom na hlavne skupiny vegetačných

spoločenstiev, ktoré boli delimitované pomocou satelitných snímok. Výsledky práce poukazujú na rozdielnú distribúciu peľových zrní z borovíc a dubového peľu. Vo väčšine prípadov peľ z borovíc zostáva v regióne borovicových lesov, sú však v tomto regióne oblasti, kde borovicové lesy získavajú iba podpriemerné množstvo peľového dažďa. Na druhej strane dubové porasty na juhovýchode Spojených štátov získavajú značné kvantily borovicového peľu. V prípade priestorového rozloženia dubového peľu je situácia iná, najväčšie množstvo dubového peľu dopadá na smrekovo-jedľové lesy a priestorová distribúcia dubového peľu je viac vyvážená. Práca poukazuje na dôležitosť detailného výskumu vplyvu lesnej fragmentácie na genetický tok. Jedným z hlavných cieľov výskumu je vybudovať model, ktorý určí vzťah medzi množstvom peľového dažďa a vegetáciou. Takýto model umožní kvantitatívny odhad peľu v závislosti na vlastnostiach vegetácie, čo má značný ekonomický význam aj vzhľadom na to, že finančné náklady na terénny výskum a čas strávený v teréne v budúcnosti rapídne vzrastú.